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Marilyne Brosseau
Ana Carrasquilla
Nicolas Saunier

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Bureaux de Montréal :
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal (Québec)
Canada H3C 3J7
Téléphone : 514 343-7575
Télécopie : 514 343-7121

Bureaux de Québec :
Université Laval
2325, de la Terrasse, bureau 2642
Québec (Québec)
Canada G1V 0A6
Téléphone : 418 656-2073
Télécopie : 418 656-2624

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Pavement Marking Retroreflectivity in Cold Regions: Survey of Practices

Marilyne Brosseau[1], Ana Carrasquilla[1], Nicolas Saunier[1,2,*]

[1] Department of Civil, Geological and Mining Engineering, École Polytechnique de Montréal, C.P. 6079, succursale Centre-Ville, Montréal, Canada H3C 3A7

[2] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)

Abstract. In the context of new retroreflectivity standards for pavement markings proposed by the Federal Highway Administration in the United States, this research was undertaken to investigate recent retroreflectivity issues faced by the ministère des Transports du Québec. First, the literature review focused on the various pavement marking materials and on the causes and solutions for retroreflectivity degradation. Solutions include recessed pavement marking or adding raised reflective pavement markers (RRPM). Second, a survey was sent worldwide to agencies with similar climate conditions to Québec. Results show that durable marking materials, such as thermoplastics, can be good alternatives to traditional water-based paint, but also that more durable ones like MMA are still not competitive when taking their much higher cost into consideration. It was also found that agencies have little information available on winter maintenance operations, even if it is one of the most influential factor in pavement marking degradation.

Keywords. Pavement marking, retroreflectivity, survey, winter maintenance, durability.

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* Corresponding author: Nicolas.Saunier@cirrelt.ca

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INTRODUCTION

Road signs and markings play an essential part in road safety and should be visible at all times. At night, vehicle headlights are often the only source of light. It is therefore important that this light source be enough to make markings and signs visible. If markings or signs reflect light back to its source, they are considered retroreflective. Pavement markings are usually made retroreflective by integrating glass beads into the pavement material.

This research was prompted by the new retroreflectivity standards proposed by the Federal Highway Administration (FHWA) in the United States (U.S.), shown in TABLE 1, and recent retroreflectivity issues faced by the Québec Ministry of Transportation (MTQ) in Canada. In recent years, the retroreflectivity durability of pavement markings in Québec has decreased. The objective of this research is to identify the causes of this problem and find solutions. This was achieved through a literature review and a survey sent to transportation agencies in jurisdictions that might face similar issues, with a focus on specific issues and solutions in cold regions such as Québec. Although other factors participate in pavement durability (presence and color), this work focused primarily on retroreflectivity.

First, the literature review focussed on new pavement marking materials, on factors known to degrade retroreflectivity, particularly on the impact of winter maintenance, and finally on existing solutions to increase pavement markings durability. Secondly, a survey of the state of practice was sent to several transportation agencies worldwide. The survey was adapted from a study conducted by Garvey et al. (1) and extended to obtain more information on marking practices in cold weather and the impact of winter maintenance.

TABLE 1 FHWA proposed retroreflectivity standards (2)

	Posted Speed (mph)		
	≤30 mph (48 km/h)	**30 - 50 mph (48 - 80 km/h)**	**≥55 mph (80 km/h)**
Two-lane roads with centerline markings only (2)	n/a	100	250
All other roads (2)	n/a	50	100
1 Measured at standard 30-m geometry in units of mcd/m^2/lux 2 Exceptions: A. When RRPMs supplement or substitute for a longitudinal line (see Section 3B.13 and 3B.14), minimum pavement marking retroreflectivity levels are not applicable as long as the RRPMs are maintained so that at least 3 are visible from any position along that line during nighttime conditions. B. When continuous roadway lighting assures that the markings are visible, minimum pavement marking retroreflectivity levels are not applicable.			

LITERATURE REVIEW

Pavement Marking Materials

Each material contains in general six primary components: binder (glue), surface glass beads (reflectors), pigment (color), solvent, additives and fillers (3) (4). In recent years, several new pavement marking materials have been introduced and are now widely used. Here is a quick review of the most common markings materials and their characteristics.

Traffic Paints

There are two main types of traffic paint: water-based and solvent-based paint. Paints are widely used, due to their low cost of application, but they are also the least durable marking materials. Traffic paints are recommended for short-term markings (under 12 months) and low traffic conditions (under

5000 vehicles/day) (5). Solvent-based paints are now used more rarely due to environmental concerns. They are banned in certain regions, such as Québec.

Epoxy
Epoxy is considered a more durable pavement marking material. In low traffic conditions, epoxy can have a service life between 2 and 4 years (4) (6), but most observed service lives are shorter, due to UV degradation, higher traffic or other factors (7) (8). Epoxy requires a relatively long drying time (about an hour), which can complicate its application. This marking material does not retain well its retroreflectivity level. On highways, retroreflectivity levels will be acceptable for about a year (9). Epoxy and paint are the most commonly used materials in Québec and Epoxy is known to last more than a year even in high traffic.

Methyl Methacrylate (MMA)
This marking material was originally created for roads with high traffic levels in extreme weather conditions (8). Two types of MMA are typically used: spray MMA and screed MMA. This material has a higher cost than other pavement markings, but its long service life still makes it an interesting option (10). The average service life of this product is between 2 and 4 years (8). MMA can be installed in temperatures as low as -1°C (Spray MMA) or even -5°C (Screed MMA).

Thermoplastic
Three types of thermoplastics are commonly used: spray thermoplastics, preformed thermoplastic and screed/extruded hot thermoplastic. This type of marking material has a good service life in any conditions, a high retroreflectivity retention level (23 months on highways (9)) and can be installed virtually in any weather conditions (11) The Alaska Department of Transportation considers thermoplastics as one of the best marking materials in cold regions, second only to MMA (10).

Preformed Tape
Preformed tape is often considered as one of the most durable pavement marking materials, but it is also one the most expensive. Service life of preformed tape is between 4 and 8 years. It is also highly resistant to snowplowing when properly installed. Preformed tape was the product with the best results in the United States' National Transportation Product Evaluation Program (NTPEP) tests sites (12).

Polyester
Polyester is not as widely used as other pavement marking materials. Since it was included in the original pavement marking survey (1), it was included in our extended survey.

Polyurea
Polyurea is also not a widely used product, but is nonetheless part of the NTPEP. In less solicited areas, polyuera still met the proposed FHWA standards after 3 years (12).

Major Degradation Factors
A Canadian study by Shahata et al. (13) has identified the following factors as having an impact on pavement marking durability:

- Material type
- Location of marking line
- Type of traffic (proportion of trucks)
- Quality of construction
- Road/highway type
- Speed of traffic
- Age of pavement marking

- Annual average daily traffic (AADT)
- Weather condition
- Surface pavement condition
- Snow removal operations

Many of these factors are common to other studies. The roadway material can also have an impact on pavement marking durability. For example, thermoplastics are a durable pavement marking material on asphalt surfaces, but they are not recommended for concrete surfaces (14).

Winter Maintenance Operations

Many studies have established a link between pavement marking retroreflectivity durability and winter maintenance operations. After a single winter, retroreflectivity levels can drop by as much as 15 % or even 40 % (12) (15). Snowplows cause the most damage to pavement markings, especially if abrasives such as sand are present on the road. Mull estimated in (16) that a single snowplow run will reduce paint retroreflectivity levels by 3.22 mcd/lx/m^2. Canadian and in particular Québec winters require many snow removal operations that cause heavy retroreflectivity losses.

Authors have created models to predict retroreflectivity levels over time. Shahata et al. (13) calibrated a model to predict the quality of pavement markings from 1 (excellent) to 5 (poor) from factors including the quantity of abrasives and the number of snowplows runs where factors. These models were considered to have a validity level between 87 % and 99 %. Quantitative models are still rare, mostly due to the fact that detailed quantitative data on winter maintenance is difficult to obtain. Information such as the number of snowplow runs on a road or the amount of abrasives and ice melters are rarely available.

Solutions to Reduce Impact of Winter Maintenance Operations

Raised Reflective Pavement Marker (RRPM)

Raised reflective pavement markers (RRPM) and their snowplowable alternative, snowplowable reflective pavement markers (SRPM), are solutions commonly used in addition to pavement markings to ensure visibility of markings in poor visibility and wet conditions. SRPM can resist many winters and therefore are a solution to ensure retroreflectivity levels on roads. On the 3345 road miles surveyed in Kentucky (17), an average of only 4.5 % of SRPM was missing. On newer or recently resurfaced roads, this average dropped to 0.4 %. Factors that determine the resistance of SRPM were defined as their shape (which in turn will influence the resistance of the SRPM to snowplow blades), the frequency of snow removal operations, the quality of installation and the pavement condition.

Material of Snowplow Blades

Snowplow blades are most commonly made out of steel or carbide. These rigid blades can easily damage pavement marking materials. Some agencies have stated using other types of blades to try and limit this damage. In a pilot project done in the state of Virginia (18), urethane was determined to cause less damage to pavement markings. Snowplow blades were also supported by small wheels to reduce the force applied on pavement markings. However, the results of this study were limited, since the pilot project was done in airports.

Recessed Pavement Markings and Pavement Marking on Rumble Strips

A widely used solution to increase pavement marking durability is recessing it either in rectangular stripes or on rumble strips. Many studies have concluded on the efficiency of this practice. In Rhode Island, retroreflectivity losses after winter maintenance was 27 % for recessed markings compared to 45 % for non-recessed markings. Recessed pavement markings were determined to have a service life twice as long as non-recessed markings and to cost less in the long run (19). Another study on recessed markings was

made in Colorado (20). For each marking material tested, retroreflectivity levels were higher with the recessed markings than with their non-recessed equivalent.

Some studies have concluded that pavement markings applied on rumble strips will also increase its service life. In an experiment done in Indiana, markings applied on rumble strips resisted better to snow removal operations than regular pavement marking. It was also mentioned that in rainy conditions, pavement markings applied on rumble strips were more visible than regular pavement markings because the marking was not applied on a flat surface (21). A Japanese study on recessed rumble strips had mixed results. Thermoplastic was much more durable when applied on recessed rumble strips but traffic paint was not. The study concluded that the fluidity of traffic paints made it more fragile when applied on rumble strips (22).

SURVEY

Description

In 2008, a survey on pavement marking methods in states with weather similar to Pennsylvania's was conducted for the Pennsylvania department of transportation (1). This survey focused on many points of interests for this study, but lacked questions on winter maintenance operations and cold weather practices. At the request of the MTQ, an extended version of the Pennsylvania survey was prepared and sent out to have more accurate information on regions with cold weather. The additional questions were sent to the transportation agencies that had responded to the 2008 Pennsylvania survey. New agencies were also contacted worldwide to have a more complete picture of pavement marking practices in cold weather regions. A total of 60 agencies were contacted, including agencies that had responded to the first survey. Agencies that completed the first set of questions for the 2008 survey were not asked to fill out the first part of the survey again. A total of 36 agencies (including those who only completed the 2008 survey) responded to the survey. The list of respondents is presented in TABLE 2.

Results

The modified survey had a total of 21 questions. The highlights of the findings will be presented and discussed in this section.

Product Costs

The first question of the survey was to specify the application costs of different pavement marking materials. Costs were converted into Canadian dollars per meter when possible. The exchange rates used were those specified by the Bank of Canada on November 16th 2011. TABLE 3 illustrates the observed results. Since some agencies answered with intervals, the average cost of application was obtained by using the center of each interval. Although this may over-simplify the data, this is the only way to create an overview of all the responses.

In some cases, there are huge differences between the maximum and minimum costs of application. It could be in part explained by a different perception by agencies of what the actual cost of application was or on the fact that availability and price of certain marking materials differs from place to place.

TABLE 2 Jurisdictions of the agencies that completed the survey

	Additional questions answered	Only first section is available
First section answered in 2008 survey	United States Connecticut North Dakota Illinois Massachusetts Michigan Minnesota Nebraska New York Oregon Wyoming	United States Alaska California Colorado Delaware Montana New Hampshire Virginia Washington West Virginia
Modified survey completed in 2011	Canada Alberta Saskatchewan Newfoundland and Labrador British Columbia Québec United States Iowa Missouri New Jersey (only 2e section) Ohio Utah Vermont Wisconsin Europe Denmark Iceland Lithuania Sweden Oceania New Zealand	Canada Ontario New Brunswick

TABLE 3 Average cost of application (intervals are used for the maximum and minimum costs)

Product	Number of answers	Average cost of application ($CAD/m)	Minimum cost ($CAD/m)	Maximum cost ($CAD/m)
Water-based paint	30	0.20	Illinois, Montana, Wyoming Oregon (0.01-0.02)	Ontario (0.25-1.75)
Solvent-based paint	9	0.40	Nebraska (0.01)	Ontario (1.25-1.75)
Epoxy	15	0.36	New Hampshire (0.03-0.05)	Québec (0.80-2.00)
Preformed Thermoplastic	5	0.86	Nebraska (0.18)	West Virginia (1.34)
Spray thermoplastic	7	0.42	Michigan (0.03-0.04)	Iceland (1.09)
Extruded/Hot thermoplastic	11	2.90	California (0.11-0.13)	Alberta (10.00-15.00)
Polyester	2	0.18	New York (0.02-0.04)	Ohio (0.32-0.34)
Polyurea	5	0.56	Michigan (0.17-0.23)	New Zealand (1.25-2.37)
Preformed tape	15	5.28	Michigan (0.35-0.53)	Québec (20.00)
Spray MMA	3	3.99	Saskatchewan (1.47)	Québec (7.00)
Screed MMA	3	7.79	Ontario (2.50-5.50)	Québec (15.00)

Frequency of Use

In question 5, agencies were asked to describe how often they used each type of marking material. TABLE 4 is the compiled data of all respondents. The total of respondents varies from one product to another, so results were presented in percentages. It should be noted that MMA was not included in the

original 2008 survey, which explains the lower number of responses. Also, since not all agencies have concrete roads, the number of answers is lower for this type of road surface.

From these results, we can see that water-based paint is still the most widely used pavement marking material, followed by epoxy and preformed tape. Other high performance materials, such as MMA or thermoplastics seem to be less popular, since fewer than half of agencies surveyed use these materials.

TABLE 4 Frequency of use of pavement marking materials

	Concrete				Asphalt			
	Often	**Seldom**	**Never**	**Total number of responses**	**Often**	**Seldom**	**Never**	**Total number of responses**
Water-based paint	72 %	14 %	14 %	29	89 %	8 %	3 %	36
Solvent-based paint	3 %	34 %	62 %	29	17 %	31 %	53 %	36
Epoxy	34 %	21 %	45 %	29	34 %	20 %	46 %	35
Preformed thermoplastic	14 %	14 %	72 %	29	20 %	26 %	54 %	35
Spray thermoplastic	10 %	21 %	69 %	29	17 %	23 %	60 %	35
Extruded/Hot thermoplastic	14 %	28 %	59 %	29	29 %	23 %	49 %	35
Polyurea	10 %	14 %	76 %	29	11 %	17 %	71 %	35
Polyester	0 %	7 %	93 %	29	3 %	3 %	94 %	35
Preformed tape	34 %	28 %	38 %	29	34 %	29 %	37 %	35
Spray MMA	0 %	7 %	93 %	14	0 %	24 %	76 %	17
Screed MMA	0 %	14 %	86 %	14	6 %	24 %	71 %	17

Service Life

In question 6, agencies were asked to evaluate the service life of all pavement marking materials. As with the average costs of application, a significant portion of answers were given in intervals. The service life was calculated by using the center of each interval. The results are presented in TABLE 5.

A very significant percentage of extreme values are from the same agencies. Oregon and Ohio have recurrent minimum values. This could have been expected if for example these agencies had particularly rough weather conditions, but it is not the case. Other factors, such as application or maintenance practices could explain the recurrence of short or long service lives.

In question 7, agencies were asked to provide service lives of pavement marking materials on different road types: freeways, multi-lane arterials, two-lane arterials, collectors and other. Since daily traffic is often mentioned as a factor in pavement marking decay, this question is very interesting. It seems that this information is hard to obtain, since most answers were either the same ranges as in the previous question, or freeways had the lower end of the range and collectors the higher. More detailed information on this subject is required so that agencies can make more informed decisions when selecting pavement marking materials.

TABLE 5 Average service life of pavement marking materials

Product	Number of answers	Average service life (months)	Minimum service life	Maximum service life
Asphalt				
Water-based paint	23	11.9	Oregon (1-24 months)	Iowa, Minnesota, Utah, Iceland (12-24) Oregon (1-24)
Solvent-based paint	17	9.3	Oregon (1-6 months)	12 months (12 agencies)
Epoxy	18	31.7	Oregon (6-12 months)	Minnesota (24-80 months)
Preformed Thermoplastic	10	41.1	Oregon (12-30 months) Vermont (12 months) Virginia (12-48 months)	Wisconsin (72 months)
Spray thermoplastic	12	29.2	Oregon (6-50 months)	Oregon (6-50 months)
Screed/Extruded hot thermoplastic	15	42.9	Oregon (5-50 months)	New Zealand (24-96 months)
Polyester	2	25.5	Ohio (24-30 months)	Ohio (24-30 months)
Polyurea	7	42.6	Oregon (6-30 months)	Minnesota (24-80 months)
Preformed tape	18	50.8	Vermont (18-24 months)	Minnesota (48-96 months) Utah (72-96 months)
Spray MMA	4	28.2	New Zealand (12-24 months)	British Columbia (36-48 months)
Screed MMA	5	54	New Zealand (24-96 months)	New Zealand (24-96 months)
Concrete				
Water-based paint	21	11.1	Ohio (1-24 months)	Iowa (12-24 months) Ohio (1-24 months)
Solvent-based paint	11	8.4	Ohio (1-6 months)	12 months (5 agencies)
Epoxy	15	32.0	Ohio (6-12 months)	Minnesota (24-80 months)
Preformed Thermoplastic	7	40.7	Ohio (12-30 months) Vermont (12 months) Virginia (12-48 months)	Wisconsin (72 months)
Spray thermoplastic	7	24.3	Ohio (6-50 months)	Ohio (6-50 months)
Screed/Extruded hot thermoplastic	8	38.4	Ohio (6-50 months)	Alberta (60 months)
Polyester	1	27.0	Ohio (24-30 months)	Ohio (24-30 months)
Polyurea	5	40.4	Ohio (6-30 months)	Minnesota (24-80 months)
Preformed tape	12	58.4	Vermont (18-24 months)	Ohio (40-120 months)
Spray MMA	1	21.0	Ontario (18-24 months)	Ontario (18-24 months)
Screed MMA	2	49.5	Ontario (30-48 months)	Alberta (60 months)

Retroreflectivity

Questions 9 through 12 focused on retroreflectivity. Agencies were first asked if they inspected retroreflectivity and 24 out of 37 agencies did so. TABLE 6 illustrates the methods used.

Agencies were then asked if they used or possessed a retroreflectometer and its model. The most common handheld retroreflectometers are either Delta LTL 2000 or Delta LTL-X, since they are used by a total of 23 agencies. The Ecodyn and Laserlux mobile van are also very common and are used by 8 agencies.

Question 11 was about the retroreflectivity standards of the agencies, if they had any. Figure 1 illustrates the results. For information purposes, the retroreflectivity standards proposed by the FHWA were included on Figure 1. FHWA standards are minimum retroreflectivity requirements; it is therefore possible that U.S. agencies with higher requirements will keep their current requirements.

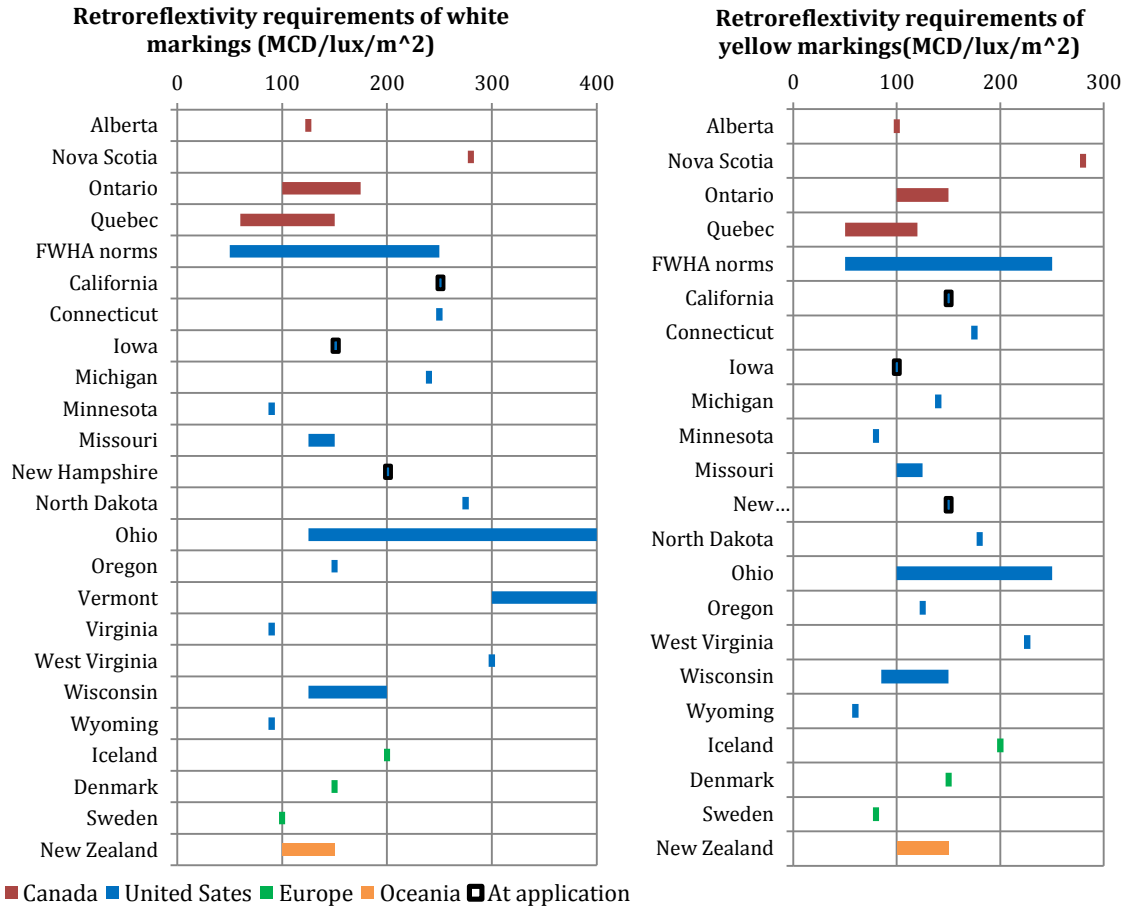

FIGURE 1 Retroreflectivity standards

TABLE 6 Retroreflectivity inspection methods

Visual inspection	Retroreflectometer	Visual inspection and retroreflectometer	Not specified
Ontario California (at application) Connecticut (at application) Missouri New York (at application) Ohio Oregon Virginia Wisconsin (continuously) Denmark (continuously)	Alberta (at application) Nova Scotia Québec Saskatchewan (continuously) Iowa Minnesota (needed basis) Wyoming Iceland Sweden (at application) New Zealand	Colorado Montana (needed basis) West Virginia	Alaska North Dakota Wyoming (continuously)

Agencies were then asked if they imposed a minimum requirement for rainy night retroreflectivity. Only 4 agencies have different requirements in wet conditions. Most agencies do not have requirements in these conditions. Connecticut and Alberta specified that the specifications presented in Figure 1 are expected to be respected even in wet conditions. The 3 agencies that had different requirements were the following:

- Virginia : 200 mcd /lux/m^2 (white markings) et 100 mcd /lux/m^2 (yellow markings)

- West Virginia : 100 mcd /lux/m^2 at all times, 200 mcd /lux/m^2 after the rain stops (white markings) et 75 mcd /lux/m^2 at all times, 150 mcd /lux/m^2 after the rain stops (yellow markings)
- New Zealand : 80 mcd /lux/m^2 at all times

Once again both U.S. agencies mentioned here have higher requirements than those proposed by the FHWA; it is therefore possible that these requirements will be maintained.

Application Conditions and Material Selection

Agencies were also asked questions on criteria for pavement marking application and material selection. In general, agencies specified that the road surface must be clean and dry to apply pavement markings. Minimal application temperatures vary from -12°C (Nova Scotia) to 10°C. Some agencies specified different temperatures depending on the type of marking material, since some materials can be applied in colder weather. Agencies were then asked what products or methods they would use in colder weather (under 10°C). Some agencies with warmer climates (Colorado, Connecticut, New Hampshire and Washington) would not stripe in such conditions. Most agencies would use cold weather markings, such as thermoplastics, MMA or cold temperature paints. In Sweden and Denmark, the roadway would be heated before the pavement marking would be applied.

To understand pavement marking material selection, agencies were asked to select which criteria they took in consideration when choosing which pavement marking material to apply. If they used criteria that were not mentioned, they were asked to specify them. The results are summarised in TABLE 7.

It is not surprising to see that the 4 most common selection criteria (traffic volume, type of road, surface condition and line placement) are factors often used in models to characterise pavement marking decay (13). Winter maintenance activities were not part of the most common factors, but it is possible that it was partly included in other criteria. For example, high traffic roads are more likely to have more winter maintenance activities than local roads. Other criteria mentioned were a visual inspection of the road, crash rates, visibility problems and the political situation of the road.

TABLE 7 Pavement marking material selection criteria

Criteria	Total of agencies that use criteria (out of 25)
Traffic volume	22
Type of road	21
Surface condition and type	21
Marking line placement	19
Winter maintenance activities	14
Number of lanes	10
Speed	8
Other	3

Rainy Night Pavement Markings Visibility

On rainy nights, visibility of pavement marking materials can decrease dramatically. In the survey, agencies were asked to describe any particular products or procedures they used to ensure rainy night visibility of pavement markings. The most common or interesting ones, and the agencies that used them, were:

- Open graded asphalt mix : California
- RRPM : Connecticut, Massachusetts, Oregon, Ohio

- Specialised markings (3M reflective tape, Rainline, Pathfinder, etc.) : Michigan, Minnesota, Oregon, Saskatchewan, Virginia, Vermont
- Textured markings : Ontario, Sweden
- Marking on rumble strips : Alberta, Michigan, Minnesota, North Dakota, Ontario, Washington
- Specialized beads (e.g. Visibeads) : Missouri, Nebraska, New York, North Dakota, Newfoundland and Labrador, New Zealand, Québec, Saskatchewan, Utah, Wisconsin
- Recessed pavement marking : Missouri, Ontario, Québec, Saskatchewan, Wisconsin

Using specialized beads seems to be the most common solution, which seems to be combined with other methods, such as recessed markings. This may reduce the damage to pavement markings and bead loss.

Durability Problems

This study was prompted by the fact that the MTQ has noticed a loss of retroreflectivity durability of pavement marking materials, particularly epoxy, in the past years. Question 17 was added to determine if other agencies have noticed a loss of retroreflectivity durability in recent years and if so, to describe the problems and the solutions implemented.

14 agencies (including Québec) have noticed a loss of durability in recent years. Out of these agencies, 9 have noticed that the recent loss of durability is due to winter maintenance operations. Winter maintenance standards are in many cases stricter today than before. This may lead to more stress on pavement marking materials and increase retroreflectivity loss.

Changes in pavement marking materials may also lead to premature degradation. Vermont and Oregon have noticed a reduction of durability since their change to more environmentally friendly paints.

Impact of Pavement Granularity

Agencies were also asked describe if changes in the pavement granularity seemed to have an impact on the durability of pavement markings. Out of the thirteen agencies that did modify the granularity of their asphalt pavements, only five claimed that using open graded pavements had an impact on the durability of pavement markings. Types of impact varied between agencies. In Oregon and Illinois, a thicker layer of pavement marking material now needs to be applied. New York has observed a significant loss of retroreflectivity since it has started used more open graded asphalt. In Massachusetts and Illinois, some types of pavements marking materials seem to be incompatible with open graded mixes. Illinois has had issues with polyurea and Massachusetts with thermoplastics. The impact of granularity of pavements should be studied in detail to determine if open graded pavements really have a significant impact on pavement marking durability.

Winter Maintenance Practices

Winter maintenance practices are often cited as a major factor in pavement marking degradation. Several questions on the subject were added in the second version of the survey. Agencies were first asked to describe their winter maintenance practices. Winter maintenance was separated into 3 practices: use of ice melters (salt or saline compound), use of abrasives (sand or other) and snowplowing. For each technique, agencies were asked to describe the criteria for application and the quantity used each year. An extra question on the type of snowplow blades was added.

There are large differences between agencies concerning winter maintenance practices. These variations are due in part to climate differences, but even agencies with similar climates use different winter maintenance techniques. Information on quantities used or the number of snowplow runs seems to be scarce. Too few agencies did not provide us with this information to present numerical results.

Ice melters are commonly used by agencies. In some cases, such as the Illinois DOT, ice melters are the main snow removal technique, representing 98 % of all operations. In other cases, ice melters are

used only on highways in addition to snowplowing. The main ice melter used is regular salt (NaCl), either in solid or liquid form. Other ice melters used are CaCl, MgCl, Apex, Geomelt and even beet juice.

Abrasives are also commonly used, but less frequently than ice melters. The most common materials are sand and grit, but some agencies use other abrasives like cinders. Some agencies use abrasives often while others use abrasives only in low temperatures (under -15°C).

All agencies use snowplows in their winter maintenance activities. Criteria for snowplow use varied from very vague (e.g. if there is snow present) to very detailed (e.g. detailed documents with several criteria). The Alberta Ministry of Transportation was the only agency able to quantify their use of snowplows. Snowplow blades can be made from a variety of materials. Carbide and steel blades are the most common, but 5 agencies also use rubber blades. Several agencies used more than one type of blades.

Solutions Found

Agencies were finally asked if they had identified methods to avoid or decrease pavement marking degradation due to winter maintenance operations. Among all the answers, the most common one is recessed pavement markings, used by sixteen agencies. Alberta and Iowa have also started using more flexible snowplow blades to protect markings. Ohio uses RRPMs to ensure retroreflectivity, but this solution was not successful for Wyoming and North Dakota. Finally, New Zealand has started using a new type of MMA, structured polymethyl methacrylate (PMMA).

Discussion

The findings of this survey confirm that pavement markings need special attention in cold regions and show that more research is needed on this subject. Even if winter maintenance activities are a known factor in pavement marking degradation, there is little information available on the subject.

Furthermore, other interesting information can be derived from the answers. Agencies were asked to describe both the cost of application and the service life of materials, making possible to determine the average cost of application per year of service. This allows a comparison between pavement marking materials with different service lives. The results are presented in TABLE 8. These results should be used with caution, since some approximations and simplifications were used to determine average cost or service life.

It is interesting to see that once their service life has been taken into consideration, many products have application costs similar to water-based paint. Epoxy, Polyester, Polyurea and thermoplastics all become viable alternatives. Even if MMA has a higher service life, it doesn’t seem to be worth the additional cost.

TABLE 8 Average cost of application per year (pavement marking materials are sorted by average cost per year)

Products	Average cost of application ($CAD/m)	Average service life (asphalt) (months)	Average cost per year ($CAD/(m*year))
Epoxy	0.36	31.7	0.1
Polyester	0.18	25.5	0.1
Polyurea	0.56	42.6	0.2
Spray thermoplastic	0.42	29.2	0.2
Water-based paint	0.2	11.9	0.2
Preformed Thermoplastic	0.86	41.1	0.3
Solvent-based paint	0.4	9.3	0.5
Extruded/Hot thermoplastic	2.9	42.9	0.8
Preformed tape	5.28	50.8	1.3
Screed MMA	7.79	54.0	1.7
Spray MMA	3.99	28.2	1.7

CONCLUSION

This study followed recent retroreflectivity issues faced by the MTQ. The results indicate that similar problems are observed in many jurisdictions worldwide. A literature review and a worldwide survey sent to agencies with climate conditions similar to those in Québec were made. This allowed determining the state of the art in this field and areas where more research is needed.

Several solutions to pavement marking durability and retroreflectivity issues have been identified in previous studies. Recessed pavement markings have proven to be a reliable method to protect pavement markings from snowplow wear. Applying marking on rumble strips seems to have similar results. Other studies show promising results when certain changes are applied to snowplows, such as changing blades to urethane or supporting the blades with wheels and therefore reducing friction between the blade and pavement markings. SRPMs have also proven to be a solution to ensure retroreflectivity levels even when pavement markings become deficient. New materials cost more than traditional traffic paint but have longer service lives. When choosing a pavement marking material, agencies can either decide to use a less durable material, such as traffic paint, and redo markings frequently or choose a more durable material that costs more at installation, but redo markings less frequently. The survey results show that the most durable pavement marking seems to be MMA, but when cost and service life are taken into consideration, epoxy, polyester, polyurea, thermoplastics and water-based paint seem to be the best economical choices. However, the environmental aspect of frequently refreshing less durable materials should also be taken into consideration. As they degrade, pavement markings may find their way into the environment. If less durable pavement markings are used, the amount of contamination may increase. There seems to be no studies on this subject.

Agencies have identified methods to preserve pavement marking durability that are consistent with the literature. Recessed pavement markings seem to be the most popular solution.

As this paper shows, more research is needed on this topic. A large and rich dataset of product tests is available from the U.S. National Transportation Product Evaluation Program (NTPEP) and should be better exploited to answer open questions. Also, as technology advances, new types of analysis are available, such image analysis. This could allow quantifying more easily and precisely certain variables such as marking presence. Further research is also needed to identify the impact, if any, of open graded pavements on pavement marking durability.

Very little data on winter maintenance operations seems to be available, even if it is known to be one of the most important factors in pavement marking degradation. Basic information, such as the number of snowplow runs, would allow the development of characterisation models and the quantitative evaluation of its impact. Future work should concentrate on obtaining more detailed information on winter maintenance operations. This work has led to a follow up ongoing project with the MTQ that will provide some answers by mining existing databases of pavement marking retroreflectivity and potential degradation factors.

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